PROCESS GRAMMARS:
A GENERATIVE APPROACH TO PROCESS REDESIGN

by

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DRAFT: Comments welcome.

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ABSTRACT

Organizations are under increasing pressure to redesign core organizational processes. This paper describes the ways in which the Process Handbook (Malone, Crowston, Lee, and Pentland, 1993) can be used to describe and redesign business processes. The Process Handbook is an electronic database of process descriptions and analysis tools. When completed, it will embody a large lexicon of process steps and constraints on the ways in which they can be combined. The Process Handbook can therefore be viewed as a kind of grammar for generating alternative process configurations. The example of a supply chain is used to illustrate the concepts.

INTRODUCTION

Organizations are under increasing pressure to adapt to more competitive environments, as reflected in increased demand for customer service, decreased cycle time for new products, globalization of upstream and downstream markets, and a widespread sense that the pace of competition has increased. During conditions of rapid change, it becomes critical to be able to adapt by rearranging and reinventing core organizational processes. This paper starts from the premise that core business processes are critical to the performance of any organization, yet they are a prime source of inertia against change (Nelson and Winter, 1982). This tension between establishing efficient, effective processes and rapidly reconfiguring them is a fundamental problem in adapting to a rapidly changing environment.

In this paper, I will describe a new research initiative that is directed at helping organizations to deal with this problem. The Process Handbook (Malone, Crowston, Lee and Pentland, 1993) is an innovative approach to the representation and analysis of business processes.[1] Still in the early stages of development, the Process Handbook uses representational techniques from computer science to provide a vehicle for describing, analyzing, and redesigning a wide variety of organizational processes. The purpose of this paper is to describe the Process Handbook in terms of an underlying grammatical model (Pentland, forthcoming) and to show how it can be used to generate new designs for organizational processes. I will illustrate the concepts embodied in the Process Handbook and their application through the example of one particularly important kind of business process: the supply chain (Lee and Billington, 1992, 1993; Lee, Billington, & Carter, 1993).

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[1] The Process Handbook project is centered at the Massachusetts Institute of Technology, Center for Coordination Science. The principle investigator is Professor Thomas Malone; co-investigators are Professor Kevin Crowston (University of Michigan), Professor Jintae Lee (University of Hawaii), and Professor Brian Pentland (University of California, Los Angeles). We are just completing the first year of a three year grant from the National Science Foundation. Those intrested in a more complete description of this project should see Malone et al (1993).
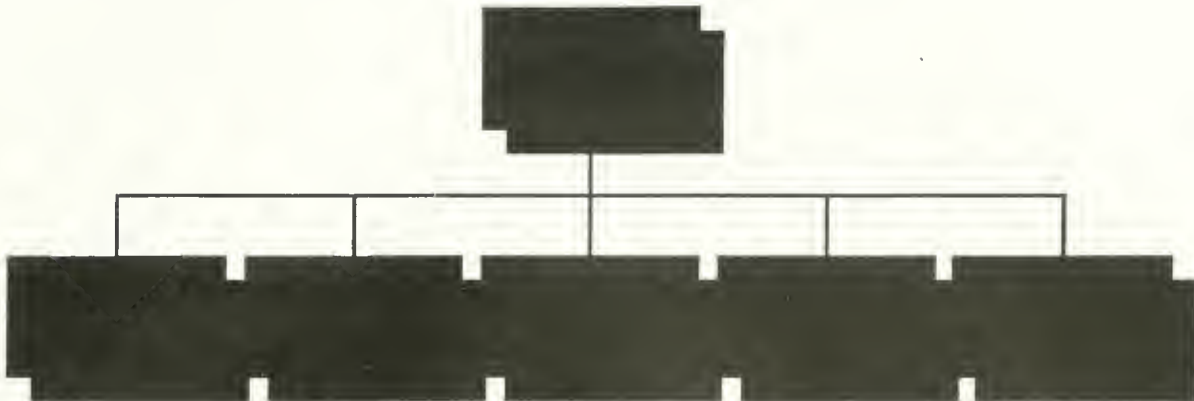
A HANDBOOK OF ORGANIZATIONAL PROCESSES

The Process Handbook (Malone, Crowston, Lee, and Pentland, 1993) is an on-line electronic database of organizational processes that will eventually encode descriptions of a wide variety of business processes, including order entry and fulfillment, product development, sales and marketing, and so on. The Process Handbook helps us to view an organizational process, such as a supply chain, in terms of generic constituents that can be arranged and rearranged to meet changing business conditions. In addition to providing a catalog of existing process descriptions, the Handbook will allow users to enter new process descriptions. It is also intended to provide a variety of analytical tools to help users evaluate the relative effectiveness of various process alternatives. In this way, the Process Handbook is intended to support the improved design of processes and the systems that support them.

The representation used in the Process Handbook combines three basic concepts from computer science to create a taxonomy of processes: decomposition, specialization, and dependencies. The sections that follow describe these basic concepts and provide simple illustrative examples.

Decomposition

Processes are decomposed into activities, which may in turn be further decomposed into subactivities. A process decomposition can be achieved by listing the "steps" or "activities" needed to complete the overall process, and is a universal aspect of any method of process description (Curtis, Kellner, & Over, 1992). For example, one might examine a basic food service transaction, which consists of the following steps, as shown in Figure 1: order the food, cook the food, serve the food, eat the food, and pay for the food (Salancik and Leblebici, 1988). In more complicated examples, one frequently finds processes nested within processes (e.g., cooking the food may be an elaborate process in itself).

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Figure 1: Decomposition of a Generic Food Service Transaction

Specialization

Processes in the Handbook are organized into a taxonomy or "type hierarchy" of the kind used in object-oriented programming systems. A familiar example would be furniture, which is specialized into tables, chairs, beds, and so on, each of which can be further specialized. The term "specialization" suggests that elements of the taxonomy are intended for a purpose; office chairs are different from dentist chairs, for example, because each serves a specialized purpose. An important property of this kind of taxonomic representation is that each element inherits features from its parents. Unlike a simple object hierarchy, however, each element in the Process Handbook taxonomy is itself a complex entity (a process) that inherits a decomposition from its parents. Thus, in the domain of food service processes, there may be many different specializations, each of which may use different technology for cooking (e.g., grilling versus baking), serving (table service versus self-service) or paying (cash-only versus credit card). These alternatives are suggested in Figure 2. Yet each kind of food service transaction inherits the basic process decomposition (order, cook, serve, pay, eat) mentioned above.

Figure 2: Alternative Specializations of a Food Service Transaction
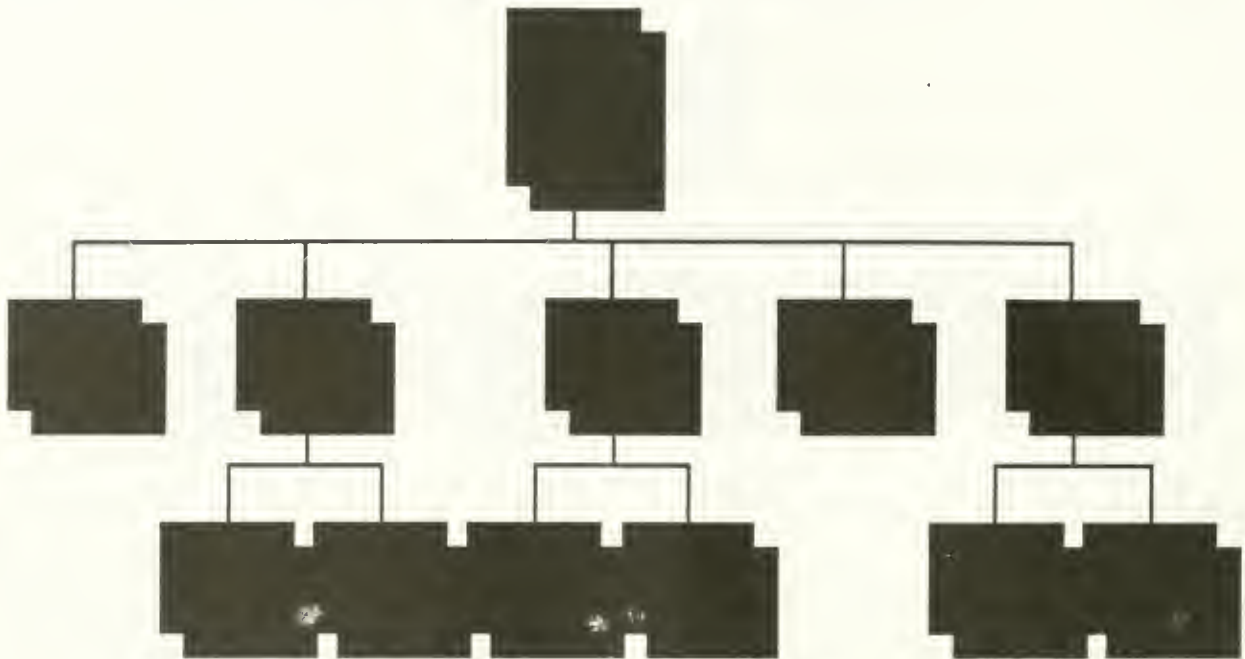
Dependencies

An important aspect of the Process Handbook is the representation of dependencies between the parts of a process. Rather than merely describing what steps are taken, the Handbook describes the relationship between these steps. Dependencies are an important kind of relationship between steps because they imply the need for coordination (Malone and Crowston 1991; forthcoming) and they imply constraints on the ways in which a process may be re-designed (Pentland, forthcoming). Dependencies are also inherited through the specialization hierarchy.

Figure 3 shows the basic kinds of dependencies represented in the Process Handbook. Unlike earlier descriptions of interdependencies (e.g., Thompson, 1967), these kinds of dependencies describe specific relationships between activities that arise as a result of some resource that they have in common as an input or an output.

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Figure 3: Kinds of Dependencies Represented in the Process Handbook

Dependency Type	Description
Producer-consumer	One activity produces a resource that is consumed by another activity (e.g., cooking produces food, which is consumed by eating)
Shared input	Two activities share the same input (e.g., two meals must be cooked using one stove)
Shared output	Two activities share the same output (e.g., two different servers are waiting on the same table)

Producer-consumer. These dependencies are very common in supply chains and many other kinds of processes. They occur whenever one activity produces a resource that is used or consumed by another activity. Resources are defined very broadly to include information and energy, as well as physical objects. Whenever a producer-consumer dependency exists, there are three aspects of it that require coordination. First, there is the temporal or sequential dependence; the "consumer" activity cannot occur before the "producer" activity. For example, one cannot eat a meal before it has been cooked. Second, there is a usability dependence; the resource produced must be usable by the subsequent activity (e.g., the blueprints created by an architect must be usable by the builder). Third, there is a transport dependency; the output of the producer must be physically available for the consumer. Thus, the producer-consumer dependency consists of sequential, usability and transport components.

Shared input. Shared input dependencies are also very common in organizations. They occur whenever scarce resources must be allocated across activities. The most common examples of shared inputs are money (in the form of capital or operating budgets), human resources and equipment. When these kinds of resources are scarce, some kind of mechanism must be put in place to allocate them across the competing activities. Note that some kinds of resources, such as information, are not depleted when shared among activities. Crowston (1991)

provides a helpful discussion of the differences in coordination mechanisms required under different assumptions about the nature of the resources being shared.

Shared output. Shared output dependencies are somewhat less common, but impose important kinds of coordination demands on organizations. One typical example of a shared output dependency is when several design teams are working on different parts of a product and must make sure that their respective parts fit together. The teams must interact to make sure that their work is compatible. Another example is when salesmen from different divisions are all working with the same customer and must be sure not to interfere with each other.

Semi-formal representations

In addition t .hese basic elements, the Process Handbook is also intended to provide a way to describe the properties of activities in semi-formal terms (Malone et al, 1987). Certain aspects of a process description, such as cycle time, can be expressed in relatively clear, mathematical terms as a mean and standard deviation. Many other aspects of a process are just as important but are impossible to formalize a way that would be comparable across settings (such as human resource requirements or institutional constraints on a particular activity). While there is no way to solve this problem, the Handbook will provide users with the capability to express these "rough spots" in free-form, unstructured text. While this limits the possibility of automated reasoning about process configurations, it allows the Handbook to encode process descriptions in a more realistic manner. It also reflects the basic design philosophy that the Handbook is to be seen as an aid to a skilled user, rather than as a panacea of some sort.

GRAMMATICAL MODELS OF ORGANIZATIONAL PROCESSES

To understand the generative potential of the representations used in the Process Handbook, it is necessary to explore the properties of the underlying representation. In particular, it is helpful to view the Handbook as embodying a kind of grammatical model.

A grammar consists of a lexicon of basic elements and rules or constraints for combining them. Grammars define sets of possibilities. The concept of grammar can be applied to any ordered sequence of elements or events, linguistic or otherwise. One can create grammars for stories (Prince, 1973; Ryan, 1979; Colby, Kennedy and Milanesi, 1990), tasks (Sandelands, 1987), political history (Alker, 1987), regular polygons (Miclet, 1986), chromosomes (Gonzalez and Thomason, 1978) and nearly anything else that can be described as an ordered set. To the extent that organizational processes can be described as ordered sets of actions, they can also be described by grammars (Pentland, forthcoming; Pentland and Rueter, forthcoming).[2]

Salancik and Leblebici (1988) used a grammatical model to represent the possible patterns of interaction in food service transactions. As mentioned above, there are five main steps in any food service transaction (order, cook, serve, eat, and pay). These steps form a generic lexicon with which to describe any such transaction. Salancik and Leblebici (1988) argued that, in addition to this lexicon, there are a set of rules that constrain the sequence in which these steps can be accomplished. For example, one cannot eat a meal before it has been cooked. One can, however, pay for a meal at any time during the transaction, even in advance of ordering, as long as the price is known. The combination of a lexicon and a set of rules for combining them allowed Salancik and Leblebici (1988) to generate the set of all possible food service transactions. Most of these transactions are recognizable as standard kinds of restaurants, such as fast food (cook, order, serve, pay, eat) or full-service (order, cook, serve, eat, pay). However, some sequences of actions that are allowed by the grammar are not commonly

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[2]There are at least two ways in which grammatical desriptions can be applied to organizational processes. Pentland (forthcoming) proposes the use of grammatical models to summarize the observed set of actions within a specific organizaitonal structure. In this sense, the structure is treated as given and the grammar is used to describe sequences of actions. As used here, the structures themselves are the elements being re-arranged. In this usage, the grammar does not describe any specific process; rather, it describes the set of all possible processes of a given kind.

observed; they appear to represent new kinds of restaurants that have not previously been discovered.

Grammatical models are generative; they can produce a potentially infinite variety of outputs from a finite lexicon and set of constraints. It is this property of grammatical models that is most interesting from the perspective of organizational design. We would like to be able to answer the question, "how else can this be done?" What other possible process configuration will meet our needs? Grammatical models are particularly well suited to this kind of question because they are able to generate new possibilities from a finite set of existing process descriptions. This is the problem to which the Process Handbook is addressed.

Grammatical Models in the Process Handbook

The Process Handbook will eventually store descriptions of a large number of different processes. These descriptions can be viewed embodying all the parts of a grammar: an extensive lexicon, syntactic constituents, and a set of templates for arranging them into complete processes. There are several ways in which the Handbook encodes grammatical information about organizational process. First, it will encode a large lexicon of specific kinds of processes. Many of these processes will be decomposed into familiar kinds of constituents, such as ordering, paying, delivering, etc. These constituents can, in turn, be generalized or specialized to identify similar elements in the lexicon. Second, by encoding dependencies between activities, the Handbook encodes important constraints on the way that activities can be arranged. There are other kinds of constraints that may be binding (such as legal or cultural requirements, for example) that may not be represented in the Handbook; users will need to be mindful of these limitations. Finally, by providing examples of existing processes, the Handbook will provide a kind of "style guide" of working processes to build from. While not explicitly intended as a database of "best practices," the Handbook would clearly make an excellent repository for such information.

Generalizing the Restaurant Transaction

To see the generative potential of the Handbook process models, we can develop our simple restaurant example a little further. Wyner (1994) is working on generalizing Salancik and Leblebici's (1988) framework to account for a larger set of transactions, such as manufacturing. The basic insight is that "cook" is a specialization of "make," "eat" is a specialization of "use," and "serve" is a specialization of "deliver." By substituting these more general terms for their more specific counterparts, Wyner observed that Salancik and Leblebici's (1988) process description can be applied to an enormous range of possible transactions, as suggested in Figure 4.

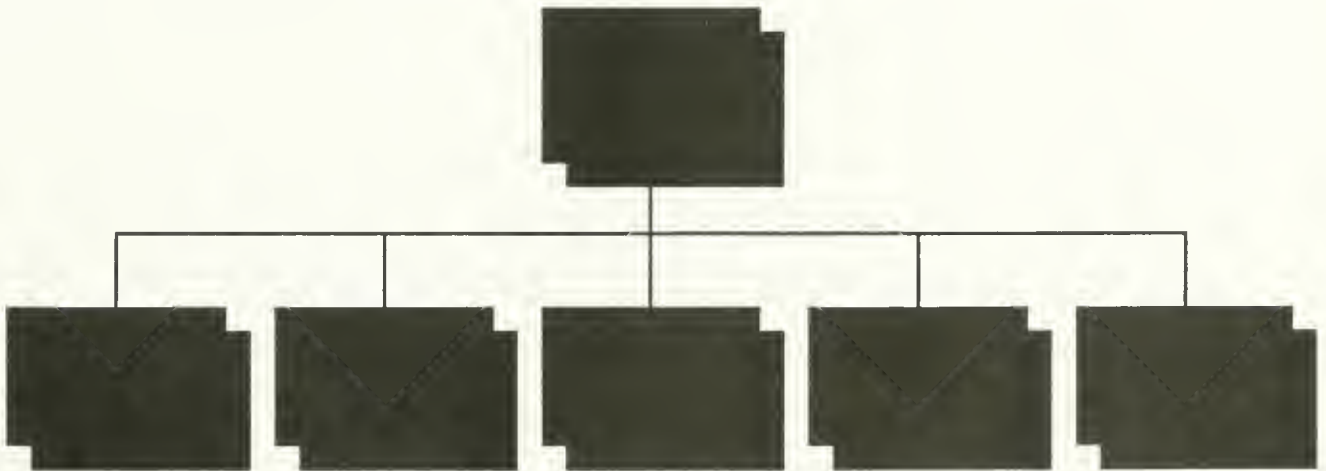**Figure 4: Decomposition of a generic transaction**

Figure 4 includes the basic steps that would be involved in any kind of transaction, whether it involves food or some other product. As in the case of restaurants, there are many different sequences in which these steps can be accomplished. For example, goods can be make to order or made to inventory. The idea of "make for inventory" suggests a critical element that is missing from the model as it stands: the notion of inventory. Hence, figure 4 represents only those transactions that do not involve inventory.

There is another extension to the process description shown in figure 4 that is even more significant: the activity of "making" most products requires the manufacturer to "order" the inputs. Supplier relationships and the coordination problems they create (especially for companies operating transnationally) are a well-known problem (Lee and Billington, 1992; Davis, 1993). It would be helpful if our representation of the basic transaction took this into account. In order to do so, one can imagine nesting several other transactions with suppliers inside the description of the "make" process. This nesting of transactions within transactions gives rise to what is commonly known as a "supply chain," which will be the focus of discussion in the rest of this paper.

SUPPLY CHAIN GRAMMARS

Supply chains are defined as the network of suppliers (factories, shipping, warehousing and distribution) that is employed in the manufacture of a product (Lee and Billington, 1992, 1993; Davis, 1993). Supply chains are the backbone of any manufacturing or retail business; they are the core process through which such organizations add value to their inputs and generate revenue. When discussed in the operations management literature, supply chains are typically reduced to the most basic elements (production, inventory, and transportation). These elements are combined to create a network that can be analyzed using a variety of formal techniques. The question we are addressing here, however, is not a formal, analytical one (e.g., what level of inventory is required to reliably fill customer orders?) but rather a creative one (e.g., how else can we do this?).

Supply chains provide a particularly interesting application of grammatical models for a variety of reasons. First, they are modularized, in the sense that each manufacturing, inventory or transportation step can be regarded as discrete. This is in contrast to many other kinds of processes, such as software support (Pentland, 1992), where the steps in the process may not be very distinct (e.g., merely describing a problems is sometimes enough to solve it). Second, supply chains are often deeply layered. This is one of the prime difficulties in managing supply

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chains, because actions at one layer (for example, a supplier's supplier delivers a bad batch of parts) can affect outcomes at other layers. Third, as this example suggests, there are many coordination constraints in a supply chain, primarily of the producer-consumer type. Because they center around the physical transfer of materials from place to place, these constraints can be relatively easily identified and studied. Fourth, the constituents in a supply chain are rather repetitive. In any given supply chain, there will be many instances of ordering, transportation, and usually inventory. These regularities make it possible to apply the grammatical framework in a meaningful way.

Three recent Master's theses at MIT have focused on using the Process Handbook to collect and analyze data about supply chains (Atkinson, 1994; Cote, 1994; Poklop, 1994). Atkinson (1994) studied the third party software acquisition process at Digital Equipment Corporation. The focus of analysis was the process used to negotiate contracts with suppliers of software that is bundled with Digital products, such as personal computers. Cote (1994) studied the pharmaceutical administration process at Emerson Hospital in Concord, MA. The focus of analysis at Emerson Hospital was the process through which patients are given the medication that is prescribed by their physician. Poklop (1994) studied the telecommunications capacity provisioning process at US West, a regional telephone operating company. The analysis at US West included not only the process of supplying new telecommunications capacity that is directly requested by a customer, but also the forecasting and planning process for new capacity in general.

These rather diverse settings revealed a variety of specialized process steps that were unique to each site. US West, for example, has to worry about road crossings and rights-of-way in planning for additional ground based telecommunications lines. DEC has to worry about maintenance and upgrades to third party software that is packaged with it's own products. Neither of this issues appear in the process of prescribing and administering drugs in a hospital, of course. Yet, at some level, these process share certain underlying structural analogies (Atkinson, 1994; Cote, 1994; Poklop, 1994).

The objective of the following section is to work out a high level, grammatical description of supply chains. Such a description will consist of abstract constituents that can provide a framework within which more detailed, specialized processes (such as those mentioned above) can be expressed. The abstract grammar is important because it provides the basis upon which comparisons and changes can be made. What follows is a tentative effort at defining a generic supply chain grammar based on the examples just mentioned, as well as examples published in the literature (Lee, Billington, and Carter, 1993; Davis, 1993).

Supply chain lexicon

The lexicon of elements in a supply chain can be defined at many different levels of detail. It is also important to realize that one can define it in terms of the objects that are typically present (e.g., plants, trucks, warehouses, purchase orders, inventory, etc.), or one can define it terms of the actions (e.g., manufacturing, shipping, storing, ordering, etc.) The approach taken here is to emphasize actions, for two reasons. First, actions are how things get done; plants and warehouses are merely the places where these productive activities take place. Second, our representation is centered around actions and the dependencies between them. Figure 5 (next page) shows a high level lexicon for supply chains.

Supply chain dependencies

Within any given supply chain, there is a set of producer-consumer dependencies that follow the flow of materials from one activity to the next. That is, one cannot assemble the product without receiving the parts, and one cannot usually receive the parts without ordering the parts. There may be various ways of accomplishing these steps, but the generic constituents share these basic dependencies. Producer-consumer dependencies are characteristic of supply chains. In addition, there may also be shared input or shared output dependencies between many of the activities. For example, if two different assembly processes share parts inventory, that would represent a common input dependency. Likewise, if there is a common output, that dependency also needs to be managed.

Figure 5: Supply Chain Lexicon

Actions	Description
Forecasting	Many supply chain activities are initiated in response to anticipated market conditions, rather than actual orders. This was exemplified at US West, where a variety of factors contributed to the increased demand for telecommunications.
Ordering	Actual orders provide the most direct stimulus for production and delivery of goods. The activity of prescribing drugs at Emerson Hospital is a typical ordering process.
Transporting	When physical goods are concerned, transport may take place by air, land, or sea. When information is being transported, various telecommunications media may be employed. At Emerson Hospital, for example, drugs are transported in special trays for dispensing to patients in their rooms.
Warehousing	Many supply chains employ buffers of finished goods or work in process. One of the objectives of supply chain design and management, of course, is to minimize the size of these buffers. The activity of warehousing consists of storing and retrieving goods, whether it occurs in a separate facility (a warehouse) or not. At Emerson Hospital, the pharmacy provides a storage facility for drugs that are used frequently at the Hospital.
Transforming	Any activity that converts inputs into outputs, such as assembling, refining, machining, editing, etc. The rather abstract term "transforming" reflects the fact that there are many different ways in which this can be accomplished. At Digital Equipment Corporation, third party software is often modified for compatibility with other elements of the system being delivered.
Shipping	Shipping is the activity of packaging and preparing goods for transportation. This may involve assembling several orders with similar destinations (e.g., containerizing for trans-oceanic shipment), or assembling the pieces of an order to a single destination (e.g., a computer system).
Receiving	Receiving is the activity of taking possession of goods that have been transported to a new location. Receiving is often an implicit step (as when patients take their medication), but is often an explicit part of a larger process, such as accounts payable.
Paying	Whenever the transfer of goods from one entity to the next takes place in a market context, there is a need for an explicit payment process. This is also the case with transfer payments between different units of the same organization. As a result, there are typically many payment steps in any given supply chain.

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Supply chain grammar

Within a typical supply chain, there may be many possibilities for how the sequential structure of work is organized. Figure 6 shows some tentative high level possibilities. The arrows in Figure 6 ("-->") can be read as "consists of."[3] Thus, the first line in Figure 6 can be read as follows: a supply chain consists of forecasting, ordering, transforming, transporting, and paying. This is one decomposition of a supply chain. An alternative decomposition eliminates forecasting and warehousing (presumably in a "make-to-order" only kind of system). If one looks further through the patterns shown in Figure 6, one finds that each of these elements of a supply chain can be further decomposed. For example, a source may consist of a plant, or it may consist of another source, inventory and shipping. Many of the constituents in the supply chain lexicon have many alternative decompositions, as in the case of transport (which may be accomplished by air, sea, truck, pipe, etc. Some kinds of constituents may be defined in terms of themselves (e.g, transforming --> tranforming, transforming...); this suggests the recursive quality of the overall process. The specific patterns here are intended mainly to be suggestive of the possibilties. We would need to collect a lot more data on different kinds of supply chains before patterns of this kind could be systematically tested.

Figure 6: Some Tentative Supply Chain Patterns

Supply Chain -->	Forecasting, Ordering, Transforming, Warehousing, Transporting, Paying.
Supply Chain -->	Ordering, Transforming, Transporting, Paying.
Transforming -->	Ordering, Receiving, Inventory, Transform, Inventory, Shipping.
Transforming -->	Transform, Transform, . .
Transforming -->	Assemble.
Warehousing -->	Store, Retrieve.
Transport -->	Shipping, Transporting, Receiving.
Transport -->	Transport, Transport, . . .
Transport -->	Air I Sea I Truck I Pipe I Wire.

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[3] Please note that this formalizm is not the usual way in which process models are expressed within the Process Handbook. These descriptions imply a strict sequence of actions that is not necessarily required by the representations used in the Handbook. In particular, the restrictions on sequence are embodies in the producer consumer dependencies, which are not explicitly represented in this formalism.

Supply Chain Transformation

Roldan (1994) identified a set of transformations that can be applied to supply chains: append, cut, rearrange, switch. Appending is when a new segment of the process is added, such as a new supplier or a new customer. Cutting is simply the opposite, when a supplier or a customer is removed from the chain. Re-arranging is when the existing parts of the supply chain are put into a different sequence. We will examine this possibility in more detail, below. Switching is when one specialization or decomposition of a process step is substituted for another. These three rules are like transformational re-write rules (Cook, 1988)-- they allow an organization to express a similar functional objective with a different combination of lexical items or syntactic constituents.

In general terms, the practical challenge facing management is to determine the constraints on the rearrangement (so as to define the space of possibilities) and then within that space, to locate an optimum configuration. I will leave the problem of optimizing to others, although there are a variety of criteria that might be included in an objective function (inventory cost, order fill rates, cycle times, etc.)[4] The creative question, once again, is how else can a given process be accomplished? To answer this question, one needs to explore the possibilities.

The possibility of applying one of these transformations to a particular supply chain is constrained, in principle, by a variety of factors. Sequential dependencies (Malone, Crowston, Lee, and Pentland, 1993) are the most common constraints. In addition, Henderson and Clark's (1991) concepts of modular and architectural change are connected here. You can change modules and sub-assemblies with in a generic design more easily that you can restructure the

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[4]This division of labor between a grammatical representation that defines a set of possibilities and some other analytical process that identifies the best possibility is similar to the division proposed by some linguists for the structure of the human speech process. They hypothesize the existance of a set of modules, each of which operates to constrain the syntax, semantics, and pragmatics (situational appropriateness) of each utterance. In our model, we are focusing on syntax.

whole thing, because markets exist for the sub-assemblies (e.g., motors, power supplies, disk drives, etc.) In other words, the sequence of actions within a supply chain tends to break naturally along lines that are determined by the prevailing design of the technology. It is relatively easy to make changes (e.g., append or cut) along these lines. But as Henderson and Clark (1991) argue, it is sometimes very important to realize that the lines have been redrawn.

**An Example: The HP DeskJet supply chain**

Lee, Billington, & Carter (1993) have described the supply chain for the HP DeskJet printer, which is shown in very general terms in Figure 7. Parts for this very popular printer were sourced from a large number of suppliers, as is typical of office equipment of this kind. In order to maximize economies of scale in the production process, manufacturing was centralized in a single "global" plant. Each regional market (North America, Asia,. and Europe) had different requirements, however, in terms of the power supply, documentation and packaging of the product. As a result, the "global" factory needed to produce a set of regional products. Worse yet, HP was required to maintain an inventory of each of these products at its regional distribution centers. Since demand in each of these markets fluctuated rather widely for this popular product, it was difficult to predict what levels of production and inventory would be required at any given time. As a result, rather large inventories were kept at each location.

Figure 7: Supply Chain for the HP DeskJet Printer
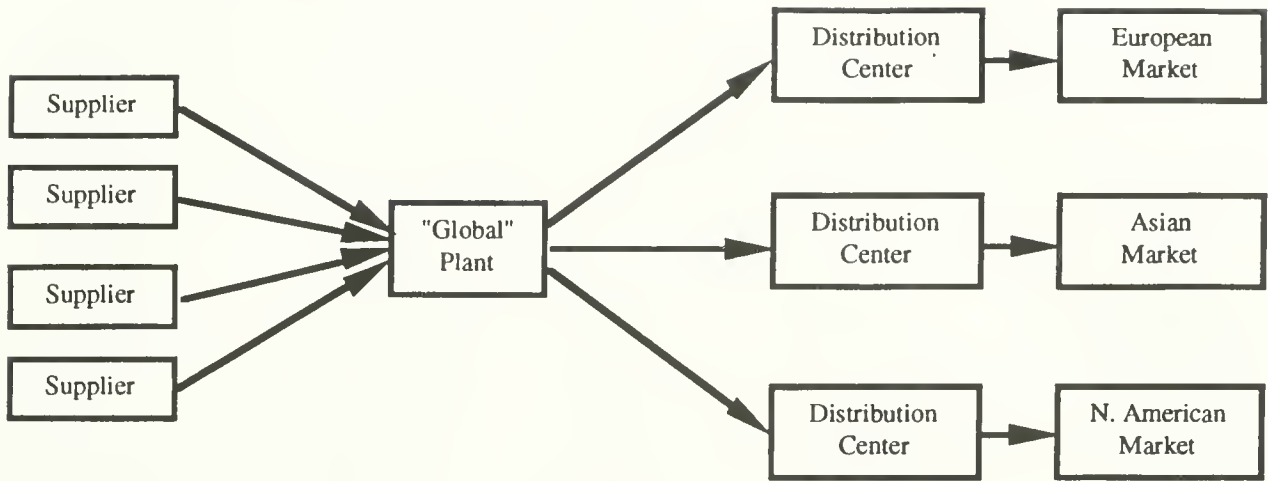
To control these inventory costs and to improve the availability of the product in each market, HP decided to modify the sequential structure of their supply chain. In particular, the decided that the global plant should produce a completely standardized product that did not include the parts that would be specific to each regional market (the power supply, documentation and packaging). To accomplish this, they had to move the final assembly steps into the distribution centers. This was a relatively easy change to implement because the final assembly and packaging steps were not overly demanding (Lee, Billington, & Carter, 1993). The reconfigured supply chain is shown in Figure 8. The effect of this change is that, since the global plant was now making a truly global product, its inventory levels could be much lower (since demand was now smoothed over the entire global market). In addition, it became possible for the regional distribution centers to engage in "lateral resupply" (shipping work-in-process between distribution centers) in response to peaks in regional demand.

Figure 8: Reconfigured Supply Chain for the HP DeskJet Printer
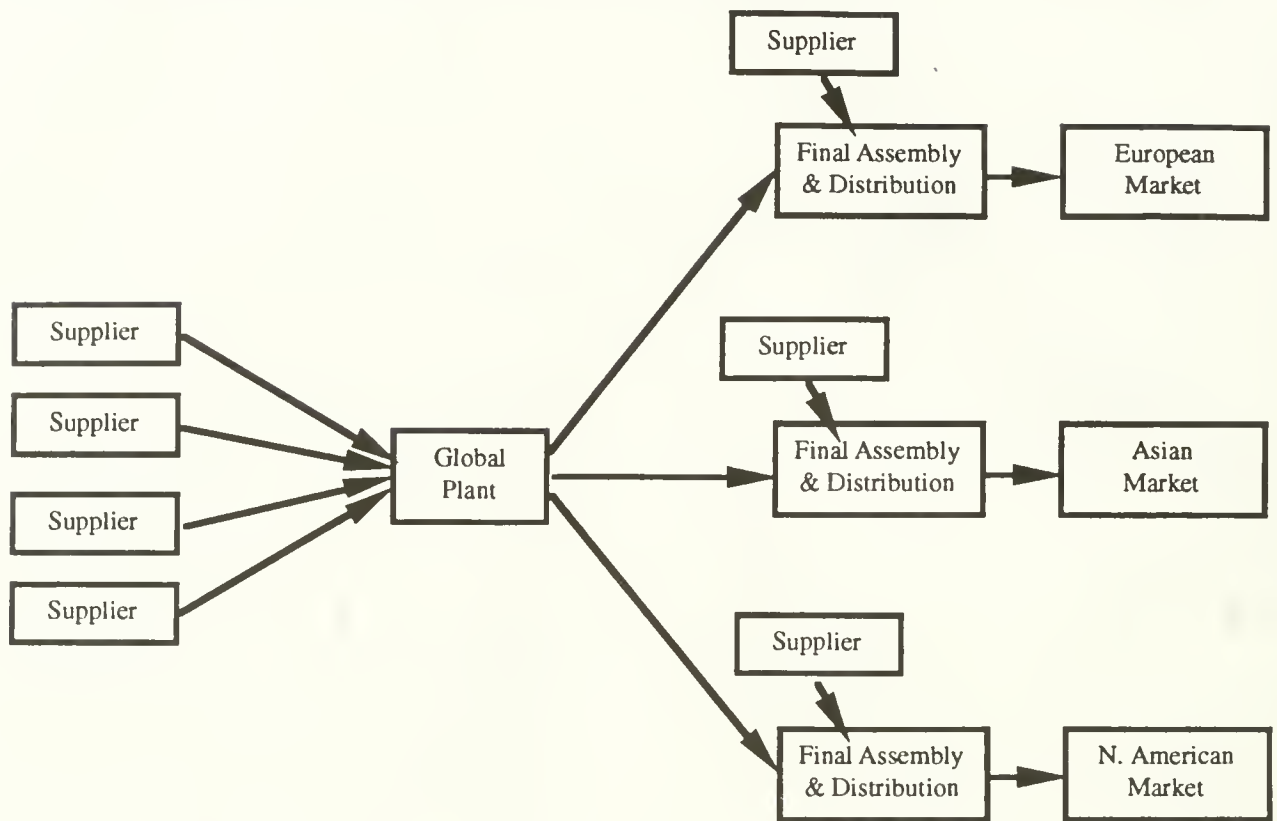
We can interpret these changes in terms of the transformational changes mentioned above. First, the steps of the process have been "rearranged." In particular, the final assembly steps have been moved until after the shipping and transportation from the global plant to the regional distribution centers. There are many other details that have been omitted from this description, of course, but that is the critical aspect of the rearrangement. Second, there have presumably been a series of "appends" and "cuts" involving suppliers of the power supplies, documentation, and packaging. It makes sense to source these products locally, if possible, since these are the aspects of the overall product that need to change for the local market.

DISCUSSION

The research discussed here is in an early stage of development, but the concepts seem very promising. We have shown that it is feasible to create taxonomic representations of

processes (Malone, Crowston, Lee, and Pentland, 1993). As I have argued here, these representations embody a grammatical model that supports the generation of new process designs. Our research agenda includes the refinement of the basic representation, the collection of data on a wide variety of processes, and the implementation of user-friendly software that can make these process descriptions available to users. We are also very interested, of course, in testing the potential of the Process Handbook to support practical design efforts of the kind described here. At the same time, we are aware of a variety of issues that need to be addressed before this approach can bear fruit.

Some limitations of process representation

One of the key difficulties in any effort of this kind centers on the way in which formal representations can obscure important details of the actual process. One advantage of our process representation is that it provides an overview of the key activities in a process (Pentland, Osborn, Wyner and Luconi, 1994), but there is always the question of whether the representation is sufficient. There are often important exceptions to a standard process that may be lost in the kind of descriptions we envision for the Process Handbook. Exception management is an important part of flexibility, of course, and of the ability of a system to gain feedback about where change is needed. From a practical point of view, this is one area that deserves special attention in the Handbook.

Another important set of concerns for process redesign revolve around the constraints on a given process. Before making changes, it is important to have a realistic understanding of what the limits to change are. Unfortunately, this kind of information is often very difficult to surface (Pentland et al, 1994), because as long as things are running smoothly, constraints are not always visible. Thus, one may unwittingly undertake changes that violate constraints that have not been captured in the model.

Another general concern has to do with the problem of generalizability across settings. The success of the Handbook project depends, in part, on our ability to create a set of generic

process constituents that translate to a wide variety of different work settings. For example, how similar is the "ordering" process at Emerson Hospital and the "ordering" process at US West. In one case, a physician write a prescription, while in the other, a private individual places a phone call (e.g., to initiate new telephone service). The ability to generate new process descriptions from the existing lexicon depends, in large part, on the lexical items within a given category (e.g., "ordering") being truly interchangeable.

Toward a process-centered organization theory[5]

At a more theoretical level, process grammars of the kind embodied in the Process Handbook suggest some interesting possibilities. In particular, grammatical models create a variety of opportunities in organizational research by providing a novel way to describe the sequences of actions that make up organizational processes. The discussion that follows is admittedly rather speculative, but it is intended to generate discussion.

Classification of processes

Organization theorists have been concerned with the classification of organizational structures and forms (McKelvey, 1982; Rich, 1992). The Process Handbook provides a conceptual framework for classification that is quite different from the typologies and taxonomies that are prevalent in organization theory. Instead of classifying organizations based on their structural features (e.g., M-form, U-form, etc.), or their industry (e.g., by SIC code), or their strategy (prospector, defender, etc.) or some other variable property, the Handbook would classify organizational units according to their internal processes. There are two main ways in which processes can be differentiated within this framework: differences in the lexicon and differences in the constraints.

Differences in the lexicon of a process are easy to identify, because they would show up immediately in the domain analysis as described above. For example, some customer service

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[5]This section is adpated from Pentland (forthcoming).

processes can dispatch a technician to your location (for example, to fix your computer), while others cannot. Processes that have the "dispatch" move in their lexicon could be called "field service," whereas processes without this move might be "walk-in" or perhaps just "hot lines." Similarly, in a retail sales operation, there may be a variety of lexical differences that create whole new possibilities for interaction and service, as in the case of catalog stores that allow customers to enter their orders directly using a computer terminal. Sequential differences are also important, as Salancik and Leblebici (1988) illustrated in their restaurant grammar. In a sit down restaurant, the sequence is *order, cook, serve, eat, pay*, but in a fast-food restaurant, it is usually *cook, order, pay, serve, eat*. The grammatical metaphor makes classification relatively easy, because it isolates differences within syntactic constituents.

Explaining the variation and distribution of processes

As one starts to develop a taxonomy of processes like the Process Handbook, it becomes possible to start asking questions about what explains the observed distribution of instances, a problem that parallels the classic problem of explaining the distribution of organizational forms (Singh and Lumsden, 1990). Furthermore, grammatical models make it is possible to predict organizational forms that have not yet been observed (Salancik and Leblebici, 1988). This is a unique and potentially very interesting contribution that is not possible with existing ways of modeling organizations. Given a set of unobserved forms, one might attempt to explain their absence.

To explain the observed distribution of processes, there are several strategies that one can adopt that roughly mirror the kinds of explanations used for organizational forms. For example, economic efficiency, institutional legitimacy, or resource availability might all be used as explanatory constructs. To the extent that the processes under consideration here are core business processes that transform inputs to outputs, economic efficiency is clearly a critical consideration. One interesting feature of the grammatical metaphor is that it suggests the possibility of separating this consideration from the internal structure of the process itself. To

see why this is so, recall that the theory of the firm treats organizations as "black boxes," without much if any consideration for internal structure. Economic theories are largely indifferent to the possible ways of organizing, except insofar as organizing effects efficiency. Likewise, pragmatics is largely indifferent to syntax, except insofar as syntax effects the force of an utterance. Excluding economic considerations from grammar does not exclude them from organization theory, but it does simplify the theoretical work to be done by each. We can begin to imagine piecing together a set of modular, interacting components that would explain the existence of observed organizational forms. Consider again Salancik and Leblebici's (1988) restaurant grammar. Their grammar explains the variety of possible restaurants without any reference to whether one form is more economically viable. This makes sense, because these are logically separate questions. Implicitly, Salancik and Leblebici (1988) are relying on the modularity of their grammar. If we were to ask questions concerning the competitiveness of the restaurants that their grammar generates, or whether the food is tasty, we would need to look elsewhere, because these questions are outside the scope of the grammar.

Comparative statics: why do processes differ?

The grammatical framework outlined here contains no endogenous explanation for change. Following the traditions of structural linguistics, grammars are generally treated as synchronic; they can be used as indicators of diachronic change, but cannot be used to explain such changes. Within the grammatical framework, one can formulate a variety of testable hypotheses concerning the effects of changing constraints on organizational processes. For example, "As constraint X changes, what new patterns or classes of action are predicted?" This is the logic underlying Malone and Rockhart's (1991) analysis of the effects of information technology on organizational processes. As the cost of this technology goes down, it reduces certain kinds of coordination constraints. As a result, new organizational forms are possible.

The grammatical method suggested here is particularly well suited to the empirical comparison of "discrete structural alternatives" (Williamson, 1991) as they are actually

practiced. Williamson (1991) maps out the structural alternatives that economize on transaction costs under various institutional regimes. While one can gain considerable insight through the study of hypothetical or idealized contracts, differences in transactions under various institutional regimes can be conveniently expressed by using grammatical models similar to the kind proposed here. Using these models, it may be interesting to observe the sequential structure of various kinds of transactions within markets, hierarchies, and hybrid forms, to see how they differ empirically. Does the lexicon or sequence of moves in a market transaction differ from the sequence of moves in a hierarchy or a hybrid form? What accounts for the differences or lack or differences? It would be quite interesting, for example, if we learned that institutional structures have relatively little effect on the configuration of transactions compared to technological or cultural considerations.

CONCLUSION

This paper has presented a brief overview of a new research project aimed at creating a taxonomy of organizational processes. Because it embodies key features of a grammar, this representations is generative; it can be used to generate new process descriptions that have not been previously observed. It is hoped that this will prove to have practical implications for managers who are confronted with the problem of redesigning core business processes. In addition, it is hoped that this approach will provoke some interest among organizational theorists. By focusing on internal organizational processes and explicitly representing their structure, I believe there are some interesting research opportunities that we have barely begun to explore.

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